

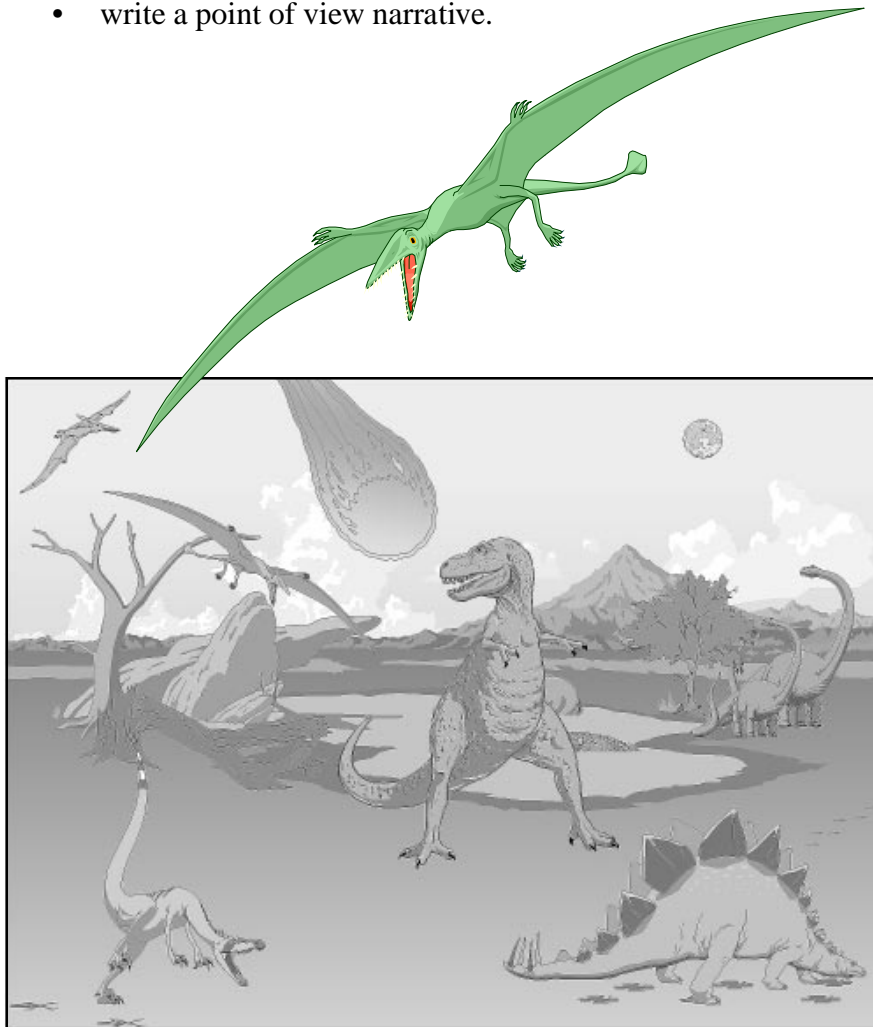
Exploring Meteorite Mysteries

Lesson 14 — Direct Hit at the K-T Boundary

Objectives

Students will:

- evaluate and apply data from a narrative to a scientific selection process.
- demonstrate or visualize simulations of some of the effects of a huge impact.
- write a point of view narrative.



“What effect do they have?”

About This Lesson

In this lesson, students explore information about the effects of large impacts.

A critical thinking activity helps students select the likely impact site associated with the extinction of the dinosaurs.

Using simple simulations students will find it easier to relate to the massive destruction caused by large impacts. Creative writing skills are developed by writing a first person narrative to illustrate the destruction.

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Activity A: Find the K-T Crater

About This Activity

This activity starts with a short informative narrative about the extinction of many species, including the dinosaurs. An asteroid impact was identified as the major reason for the long lasting global changes that killed so many living things. But the location of the large crater, caused by the impact, was not immediately obvious. Like the scientists, the students will be asked, “Where is the crater?” Students will develop the criteria for evaluating crater candidates from the background narrative information. In teams they will evaluate selected craters to see which one(s) might have caused the extinction of the dinosaurs.

Materials for Activity A

- ☐ Student Background
(pgs. 14.7-14.8)
- ☐ Geographic Features
Suspect List (*four sets are provided,*
pgs. 14.9-14.12)
- ☐ Geographic Features
Teacher Key (pg. 14.6)
- ☐ physical maps(s) of the world
- ☐ overhead projector
(*optional*)

Objective

From a narrative, students will:

- select criteria and then apply them to a scientific problem by using critical thinking skills.

Background

Sixty-five million years ago three quarters of the life forms on Earth became extinct. The most well-known group to die out were the dinosaurs. However, birds may be lineal descendants of one group of dinosaurs. Other species that became extinct were the ammonites (marine molluscs like the chambered nautilus), rudistid clams (so abundant that they formed huge reefs), and whole groups of small marine organisms. The only groups of animals that were not affected lived deep in the oceans. Some land animals like the early mammals survived also. This extinction marks the end of the Cretaceous period of geological history and the beginning of the Tertiary period. Rocks that formed during these distinct periods are recognized by their fossils, which are enormously different because of the great extinction. As a shorthand (or jargon), geologists call this geological instant the K-T boundary (K for the German word for Cretaceous; T for Tertiary).

The extinction of the dinosaurs has been a source of scientific speculation. Hypotheses about the cause of the extinction have included:

- it wasn’t a single event, but a series of unrelated local extinctions;
- the extinction was a slow decline in numbers and diversity, not a catastrophe;
- the extinction was caused by a rapid change in climate from warm and wet to cool and dry;
- the dinosaurs became an evolutionary dead end and could no longer adapt to minor changes in their environment;
- living things were killed by the effects of massive volcanic eruptions (specifically those in the Deccan region of India);
- the effects of a meteorite impact caused the extinctions.

Until 1980, each of these hypotheses had strong adherents and there was no consensus at all. In that year, a crucial paper was published in *Science* that thrust the meteorite impact hypothesis into prominence and eventual acceptance by most scientists.

The K-T boundary had been investigated for many years as scientists searched for the cause of the extinctions. The rocks seemed to indicate a global catastrophe. Rocks at the exact boundary are not exposed at the Earth's surface in very many places. Some of the best exposures are in northern New Mexico, southern Canada, Italy, Spain, Denmark, and New Zealand. At all of these sites, the K-T boundary is defined by a thin layer of grayish clay. Rocks at these sites include sandstones from ancient river valleys, limestones from ocean reefs, and cherts from the ocean floor. The gray clay is present in all of them. Cretaceous fossils, marine or terrestrial, are present below the gray clay and are never found in rocks above the gray clay.

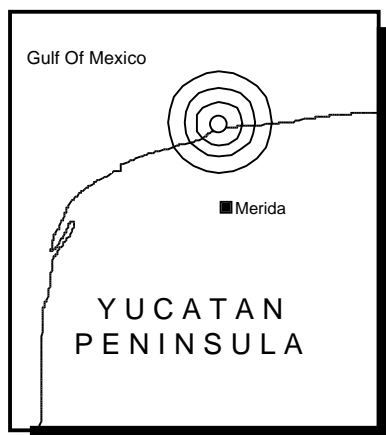
Scientists at the University of California at Berkeley (led by Nobel laureate Walter Alvarez and his son Louis) decided to investigate the clay layer at the K-T boundary to see if they could determine just how much time was represented by the gap between K and T times. A meteorite researcher suggested that the fairly constant inflow of micrometeorites that contain trace amounts of the element iridium might yield a measure of the time. Iridium is extremely rare in rocks from the Earth's surface, averaging about 0.1 parts per billion, but is much more abundant in common meteorites at about 500 parts per billion. Also, analyses for such small quantities of iridium is relatively cheap, easy and reliable using a technique called neutron activation analysis. Alvarez and his co-workers collected samples of the K-T gray clay and the surrounding rocks and analyzed them for iridium. They found an extremely high concentration of iridium (from 1 to 90 parts per billion). The iridium concentration was so high that at expected micrometeorite fall rates, the gap would represent tens of millions of years. This time sequence was not likely so they were forced to look for another reason for the unexpected amount of iridium.

Thus, the discovery reported by Alvarez, of the worldwide distribution of iridium from meteorites, has added to the evidence that a large meteorite impact did occur at the K-T time. Many scientists conducted investigations that would link this new information with the mass extinction of species.



The extra iridium at the K-T boundary also allowed Alvarez and his co-workers to estimate the size of the impacting meteorite. They calculated how much extra iridium, in grams/cm², had fallen at each of the K-T sites and computed the average iridium fallout. Assuming that the iridium had been originally deposited worldwide, they calculated their extra iridium values and

Painting courtesy of Don Davis®.



computed the total iridium fallout over the Earth. Their total iridium could have been supplied if the impacting “meteorite” were 10 kilometers in diameter, and made of ordinary chondrite material. An object this size can hardly be called a meteorite; it was an asteroid.

Once the iridium excesses in the K-T clay were known, other scientists began looking for additional evidence for a meteorite impact at the K-T boundary time. In the gray clay they found other features consistent with a meteorite impact, including grains of the mineral quartz that showed the effects of enormous shock pressure, and globules of melted rock that could have been formed in an impact. Scientists also found soot in the clay layer — enough soot to suggest that enormous fires consumed much

of the Earth’s vegetation. In the rocks below the gray clay, they also recognized deposits from enormous ocean waves that might have been tsunamis caused by an impact. In addition, they found broken rock in unusual places that suggested earthquakes (which could have been triggered by an impact).

The impact of a 10 km diameter meteorite (actually a small asteroid) must have produced a circular crater, probably more than a 150 km in diameter. A crater that size would likely have multiple ring structures, like the larger craters on the Moon. Although remnants of a few large craters like that are known on the Earth, they are all much older than the 65 million year age of the K-T boundary. The lack of a known crater made many scientists suspicious of the whole meteorite impact hypothesis, and inspired others to look for the impact crater. Many features around the world were suggested and investigated as possible impact sites.

The work centered first on North America because the largest fragments of shocked rock were found there. The Manson meteorite crater, beneath Iowa, was first targeted because it formed about 65 million years ago. But Manson is only 35 kilometers in diameter, probably too small to have caused global devastation and too small to have been made by a 10 kilometer asteroid.

Then the search focused on the Caribbean area, because the clay layer was thickest there, and had the largest rock fragments and globules of melted rock. Finally, suspicion focused on an unusual sub-surface structure on the northern coast of Yucatan (Mexico), centered under the town of Chicxulub. Studying rocks from drill cores of the area and data from remote sensing methods (gravity measurements, seismic profiles) showed that the Chicxulub structure is a meteorite impact crater. The most recent estimate of its size is 300 kilometers across, certainly large enough to have caused a global environmental catastrophe.

The effects of the meteorite hitting the Earth can hardly be described. As the meteorite hit, all life within about 300 km (the size of the eventual crater) would be vaporized instantly. Then the hot blast wave from the impact explosion would kill all life for several hundred kilometers in all directions. Farther out, the blast wave would kill, deafen and disorient many animals. In the ocean, the shock from the impact would generate enormous, world-wide tsunamis, perhaps with waves a kilometer tall. Gigantic hurricanes might also be triggered. In the Earth, the shock from the impact would be felt as huge earthquakes, and would set off other earthquakes over the whole globe.

Ejecta from the impact (sand-sized and larger) would shoot out and rain down for thousands of kilometers around. Other ejecta would leave the Earth’s atmosphere but not Earth’s gravity; it would return to Earth as meteorites so abundant that their heat would “broil” the Earth’s surface and set off

wildfires over the whole planet. Over the impact site, a mushroom cloud would rise, carrying dust from the explosion far into the stratosphere. This dust would mingle with the soot from wildfires to form a world-wide haze so thick as to block out all light from the sun. Over time, without the Sun's heat, surface temperatures on the Earth would drop 20-30°C. The combined effects of the fires, the darkness, and the cold must have devastated life and caused the collapse of almost all ecological interrelationships. Months later, when the dust cleared and the Sun finally shone again, only some seeds and the most enduring animals would still be alive. Three quarters of all species would die in the next few years, due to the loss of the ecosystems on which they depended. Early shrew-like animals were the only mammals so far discovered to have survived the disaster.

Procedures

Advanced Preparation

1. Review background.
2. Read and be familiar with the Teacher Key for Geographic Features.
3. Prepare envelopes containing sets of Geographic Features: Suspect Lists.
 - one set of four features per envelope, per team
 - repeat sets if there are more than four teams

Classroom Procedure

1. Read the Student Background as a group or individually.
2. Ask "Where is the Killer Crater?" and "What criteria (parameters) would you use to narrow the list of suspect features?"
Note: Some students may already know the name or location of the likely crater. Encourage them not to reveal the name and remind them that, like scientists, they must present proof and logical reasons for their crater choice not just "I read/saw that it was down in the Yucatan."
3. Brainstorm the criteria as a class. Take all suggestions and then combine and focus on the categories listed below. Some classes may develop only three criteria and some may have four. Be flexible, but do not focus on age alone, the true age of a feature may be difficult to determine. (Criteria: **Shape, Size, Target Material, and Age**)
4. Divide the class into teams of 3-4 students (more if necessary).
5. Distribute the envelopes of "Suspect Features", keeping the numbered groupings so that each team will have a variety of criteria to assess.
6. Ask each team to assess whether their assigned features are "likely," "unlikely," or "possible" candidates for the "Killer Crater." Maps may be used.
7. Have each group report their findings to the class. (A simple list on the chalkboard or a chart may be developed if needed.)
8. Have the class prioritize the list of craters, from "most likely" to "maybe."
9. Provide information from background as needed.

Vocabulary

crater, meteorite, asteroid, impact, iridium, clay, shock, quartz, fossil, Cretaceous, Tertiary, catastrophe, soot.

Questions

1. Could there have been more than one impact that contributed to the global catastrophe? Justify your answer.

Extensions

1. Ask students to bring articles from books or magazines that give more background information.

Teacher Key

Geographic Features

Feature/Location	Origin	Shape	Size (dia.)	Target Material	Age (My*)
GROUP 1					
Acraman <i>Australia</i>	impact	hexagonal/ circular	160 km	continental rocks	600 My
⇒ Manson Structure <i>U. S.</i>	impact	circular	35 km	continental rocks	65 My
Valle Grande <i>U. S.</i>	volcanic	circular	22 km	volcanic rocks	2 My
Elgygytgyn <i>Russia</i>	impact	circular	?	continental rocks	3.5 My
GROUP 2					
Crater Lake <i>U. S.</i>	volcanic	circular	8 km	volcanic rocks	6,000 years
Crater Elegante <i>Mexico</i>	volcanic	circular	1 km	volcanic rocks	recent
✓ Chicxulub Structure <i>Mexico</i>	impact	circular with concentric rings	300 km	continental rocks	65 My
Vredefort <i>South Africa</i>	impact	circular with concentric rings	140 km	continental rocks	2 billion yrs
GROUP 3					
⇒ Kamensk <i>Russia</i>	impact	?	35 km	continental rocks	65 My
Charlevoix <i>Canada</i>	impact	semi-circular	46 km	continental rocks	357 My
Iceland <i>Iceland</i>	volcanic	circular	400 km (larger on ocean floor)	oceanic volcanics	20 My
Lake Toba <i>Indonesia</i>	volcanic	elongate	50 km	volcanic rocks	75,000 yrs
GROUP 4					
Lake Baikal <i>Russia</i>	tectonic movement	elongate	650 km x 8 km	continental rocks	25 My
Sudbury <i>Canada</i>	impact	elliptical	max 200 km	continental rocks	1.85 billion years
⇒ Deccan Traps <i>India</i>	volcanic	roughly circular	520,000 sq.km	volcanic rocks	65 My
Barringer (Meteor) Crater/U.S.	impact	circular	1.2 km	continental rocks	49,000 yrs

* my = million years

✓ designates likely crater candidate

⇒ designates possible choices

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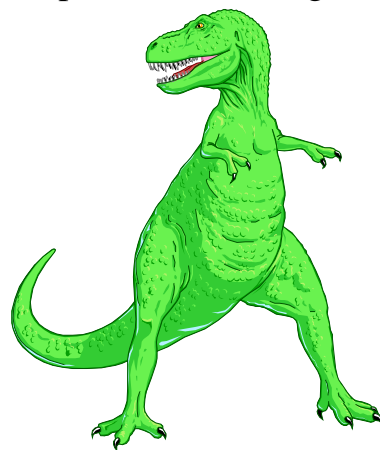
Student Background

The death of the dinosaurs was part of a large extinction — a time when three quarters of the kinds of life (species) on Earth were killed. Most scientists are convinced that the dinosaurs and other life forms died when a giant meteorite hit the Earth. You may have heard about the crater from this impact. Just like the scientists who study the death of the dinosaurs, you too can use reason to choose which crater was the killer.

The dinosaurs died out about 65 million years ago, along with many kinds of plants and marine animals, especially ones that lived in shallow water. This change in life on Earth, and the fossils left behind, marks the end of the Cretaceous period of geological history and the beginning of the Tertiary period. Geologists commonly call this time the K-T boundary. In many places, the rock at the K-T boundary is a few centimeters of clay. Below the clay are abundant fossils of Cretaceous animals (dinosaurs or marine animals, depending on the rocks); above the clay layer, in the same kind of rocks, the fossils are gone. This clay layer marks a global ecological catastrophe, the extinction of three quarters of the life forms on Earth.

One idea was that the K-T extinctions were caused by meteorite impacts. In 1980, scientists from the University of California at Berkeley set out to test this idea. They thought that the K-T clay might contain meteorite material, and that the element iridium might be a good “fingerprint” for a meteorite impact. Iridium is a rare metal, much like platinum, and about 5000 times more abundant in most meteorites than in Earth rocks. The scientists analyzed samples of the clay, and found that it had up to 400 times the iridium of the surrounding rocks! This result proved that a huge meteorite had hit the Earth at the time of the K-T extinction. A meteorite of about 10 kilometers in diameter could have provided all of the iridium in the worldwide clay layer.

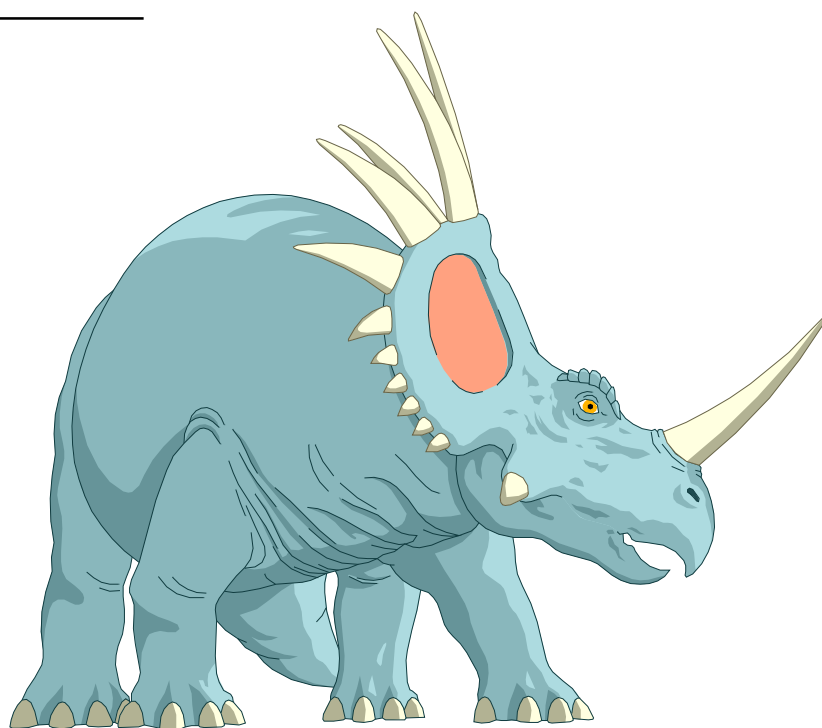
But the proof of a meteorite impact left many questions unanswered. How could a meteorite impact have caused massive deaths over the whole world? And where was the crater caused by this meteorite?



How could a meteorite impact have caused a global ecological catastrophe? Everything at the impact site would have been vaporized, and the blast wave would have killed all life for hundreds of kilometers around. Earthquakes, tsunamis, and hurricanes would also have killed many animals. But how could the effects have been global? The evidence is in the K-T clay, which is found all over the world. That clay was originally dust from the impact, and must have spread throughout the atmosphere, and then settled out to form the clay layer. In addition, the K-T clay is rich in soot, suggesting that the meteorite impact was followed by huge fires over much of the globe. The dust and soot would have blocked out the Sun for months, and temperatures would have dropped 20 to 30°C. Only the most enduring animals and seeds could have survived until the air cleared and the Sun shone again.

And where did the killer meteorite land? Where is the smoking gun? The impact of a 10 km meteorite must have made a crater, a huge circular scar, somewhere on the Earth's surface, similar to craters on the Moon, Mars, and other planets. The K-T clay again holds clues, now in the form of grains of the mineral quartz, heavily shocked by the meteorite impact. Quartz is very rare in rocks from the ocean basins, so the impact crater is likely to be on a continent or continent edge.

But exactly where? Which crater pulled the trigger on the dinosaurs? This is your chance to pick the killer crater from this line-up of suspects. Just don't bother looking for a motive.



Acraman - In South Australia, Lake Acraman is a hexagonal salt lake about 20 km in diameter at 32°S, 135.5°E. Surrounding the lake are two, much larger, circular structures, which are barely visible in aerial or space shuttle imagery; the largest structure is 160 km in diameter. Rocks in the area are deformed, and a belt of broken and melted rock is present 300 km to the East of Acraman. The broken and melted rock formed about 600 million years ago, which may be the age of the Acraman structure.

Manson Structure - The Manson Structure, beneath the surface in Iowa at 42.5°N, 94.5°W, is detectable only through geophysical means (seismic profiles). It is a circular ring of granitic rock, 35 km in diameter, buried under hundreds of feet of other rocks which appear to have covered over the ring. The rocks in the Manson structure are severely broken. They were subjected to great shock pressures, and melted. The age of the Manson structure is about 65 million years.

Valle Grande - The Valle Grande is a circular basin, 22 km in diameter, in the mountains of central New Mexico at 36°N, 106.5°W. The edge of the basin is a sharp scarp, and the land slopes away on all sides. Rocks at the wall of the basin are broken and jumbled together. Within the basin is a central peak surrounded by a ring of smaller peaks. Rocks in the Valle Grande are all volcanic, with ages of younger than 2 million years.

Elgygytgyn - Elgygytgyn is a circular lake (the meaning of the name in the local tribal language) in easternmost Siberia, Russia: 67.5°N, 172°E. Around the slightly raised rim of Elgygytgyn is a ring of broken and partly melted rock. Farther away there is a halo of fractured and strongly shocked rocks. There are no volcanoes or recent volcanic rocks in the area. The crater formed 3.5 million years ago.

Crater Lake - Crater Lake is a circular basin, 8 kilometers in diameter, at the peak of a 2400 meter tall mountain in Oregon at 49°N, 122°W. The edge of the basin is a sharp scarp, and the mountain slopes away on all sides. The basin is filled with water. One peak forms an island in the basin center. Crater lake formed 6,000 years ago.

Crater Elegante - This circular depression, about 1 kilometer in diameter, is in northwestern Mexico at 30°N, 115°W. The crater has steep sides and a raised lip; the land surface slopes gently away from the crater in all directions for a kilometer or so. The crater is near the flanks of a large volcano, Cerro Pinacate, which is surrounded by many cinder cones and lava flows.

Chicxulub Structure - Chicxulub is a circular structure in bedrock beneath the Yucatan Peninsula, Mexico, consisting of concentric rings of uplifted bedrock centered at 23°N, 90°W. The largest ring is 300 km in diameter. The Chicxulub structure is buried under a great thickness of limestone, and has been mapped by remote geophysical methods (gravity and seismic profiles). Within the structure are lava rocks and minerals which have been shattered or subjected to high pressure. The Chicxulub structure is apparent at the Earth's surface only as a series of sinkholes over one of the concentric rings. The Chicxulub structure formed 65 million years ago.

Vredefort - The Vredefort ring appears as concentric circles of ridges in bedrock in South Africa at 27°S, 27.5°E. The outermost ring is 140 km in diameter and is partly covered by younger rocks. Vredefort does not look like a crater now, but it is thought to be an eroded crater. It formed 2 billion years ago.

Kamensk - The Kamensk crater is an impact scar in south-central Russia, at 48°N, 40°E. It was formed 65 million years ago and is 35 km across. Because of political instability in the region, nothing more is known about the Kamensk crater.

Charlevoix - The Charlevoix structure is marked by a semicircular valley along the St. Lawrence River in southern Quebec, Canada: 47.5°N, 70°W. If the structure was originally circular, its southern half is now under the river. Outside the valley is a band of hills, giving an overall diameter of 46 kilometers (if the structure is circular). Rocks around the structure have been strongly deformed. In the center of the semicircular valley is a central peak, composed of broken and melted rock. The age of the melted rock is 357 million years.

Iceland - This roughly circular island is located in the North Atlantic at 20°W, 65°N. It sits on the Mid-Atlantic Ridge, a volcanically active spreading center. The island is about four hundred kilometers in diameter and has many lava flows and active volcanic vents. Scientists estimate the age of Iceland to be as much as 20 million years old.

Lake Toba - Lake Toba is located in an elongate basin structure on the Island of Sumatra, Indonesia at 3°N, 99°E. The land slopes gently away from the outer edge of the fifty kilometer basin. The surrounding volcanic ash flows have been dated at about 75,000 years old.

Lake Baikal - This beautiful, elongate lake is located in southeastern Russia at 107°E, 52°N. It is the Earth's deepest continental depression with the total depth of water plus sediments at over 9 km. The lake is 650 km long and 8 km wide. The oldest sediments are estimated to be 25 million years old.

Sudbury - The Sudbury structure is an elliptical area of igneous rocks and sediments in southern Ontario (Canada) at 46.5°N, 81°W. Sudbury is inferred to be an impact crater because rocks around it show characteristic features of intense shock. Now the Sudbury structure is 140 km by 50 km, and may have been as large as 200 km diameter when it formed, 1.85 billion years ago.

Deccan Traps - The Deccan structure, located at 75°E, 20°N, covers a large part of west-central India. About sixty-five million years ago huge lava flows formed a thick, roughly circular area of approximately 520,000 square kilometers.

Barringer (Meteor) Crater - The Barringer Crater is a circular hole in the ground in northern Arizona, 35°N, 111°W. It is 1.2 km in diameter. Many pieces of iron meteorite have been found scattered around the crater. It is estimated to have formed 49,000 years ago.

Lesson 14 — Direct Hit at the K-T Boundary

Activity B: Global Ecological Disaster

Objective

Students will:

- visualize or physically demonstrate simulations of some of the effects of a huge impact.

Background

National Geographic Sept. 1986. See Background from Lesson 14, Activity A (pgs. 14.2-14.5).

Procedure

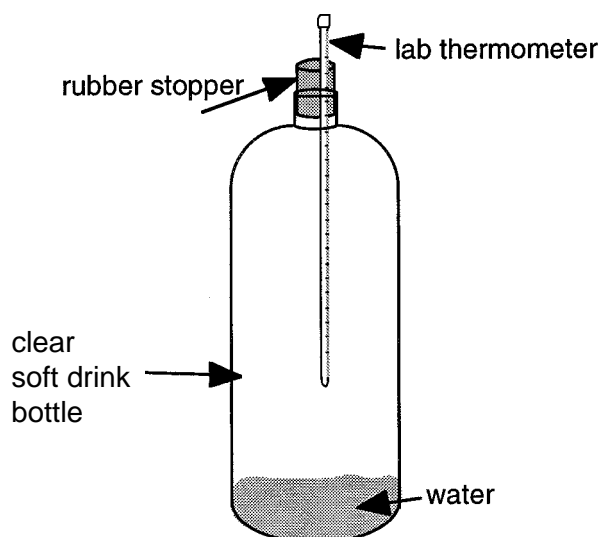
Advanced Preparation

1. Gather materials.
2. Review background material.

Classroom Procedure

Atmospheric Changes (see diagram)

1. Put water in each bottle to a depth of 1 cm.
2. Place a stopper in each bottle, insert one thermometer through each stopper.
3. Place the two prepared chambers where all students may observe.
4. Distribute the Atmospheric Changes Data Sheet.
5. Have the students predict what will be the effect of sunlight on the chambers if one chamber contains smoke particles.



About This Activity

In this activity students will use simple simulations to develop a better understanding of the short term and long term changes that happen when gigantic impacts occur on Earth. These exercises may be done as demonstrations, experiments or as verbal visualizations, i.e. "Think about what happens when you throw a large rock in a puddle!".

Materials for Activity B

- ☐ 2 two liter clear soft drink bottles
- ☐ 2 one hole rubber stoppers or styrofoam or clay to block top
- ☐ 2 lab thermometers (*long*)
- ☐ water
- ☐ paper (*wooden splints work well also*)
- ☐ matches
- ☐ light source (*sunlight is best but lamp or overhead will work*)
- ☐ Atmospheric Changes Data Sheet for temperature and time (*pg. 14.16*)
- ☐ two pie pans
- ☐ rock or other object 3-5 cm diameter
- ☐ water to fill pan
- ☐ flour to fill pan
- ☐ pencil/pen

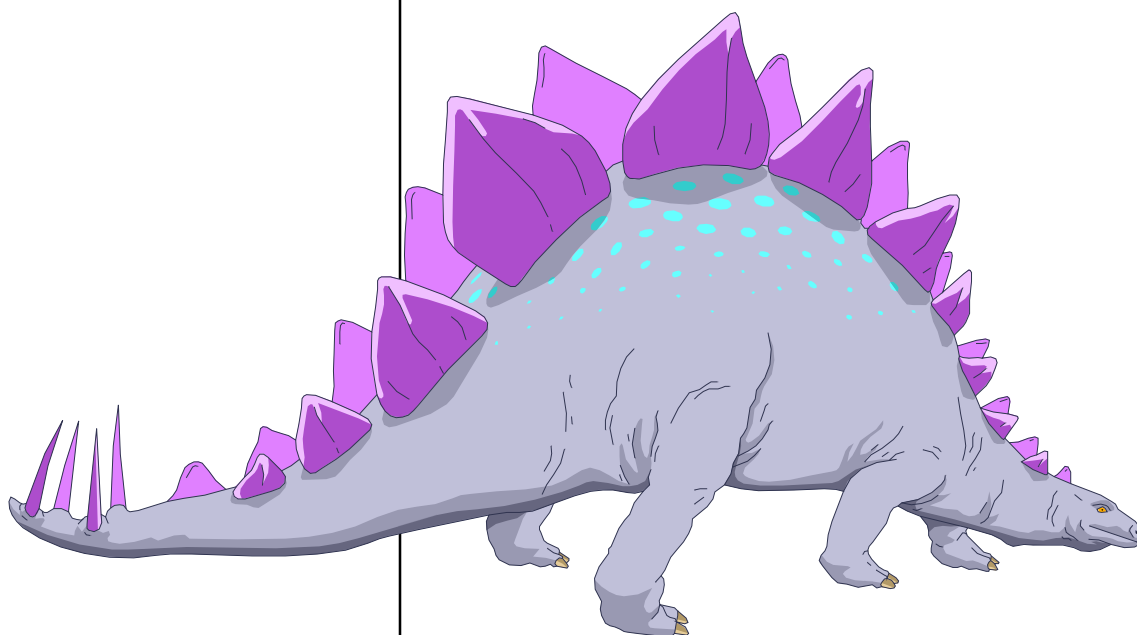
6. Put burning paper (splint or wooden stir stick) in one chamber and immediately replace stopper (this may be done before students are present).
7. Allow time for the temperature to come down to the **same temperature** as in the control container.
8. Place chambers in sunlight (or use lamp if necessary).
9. Using data table, students record temperature of each chamber at 1 minute intervals or more, allowing enough time to show a significant difference in temperature).
10. Based on the results, students should evaluate their hypotheses.

Tsunami

1. Fill one pie pan with water.
2. Drop rock in water.
3. Observe what happens.
4. Compare and contrast the effect of the “rock” to the possible effect of an asteroid over 10 km in diameter with an impact speed of about 15 km per second.

Ejecta and Base Blast

1. Fill one pie pan with flour.
2. Drop rock or large heavy object into flour (layered with another fine powder if desired).
3. Observe the ejecta and fall out.
4. Discuss the probable similarities and differences between this demonstration and what happened at the impact site at Chicxulub.



Lesson 14 — Direct Hit at the K-T Boundary

Activity C: You Were There!

Objective

Students will:

- write and illustrate a point of view narrative on the extinction of the dinosaurs.

Background

Consult the Background in Lesson 14, Activity A (pgs. 14.2-14.5).

Procedure

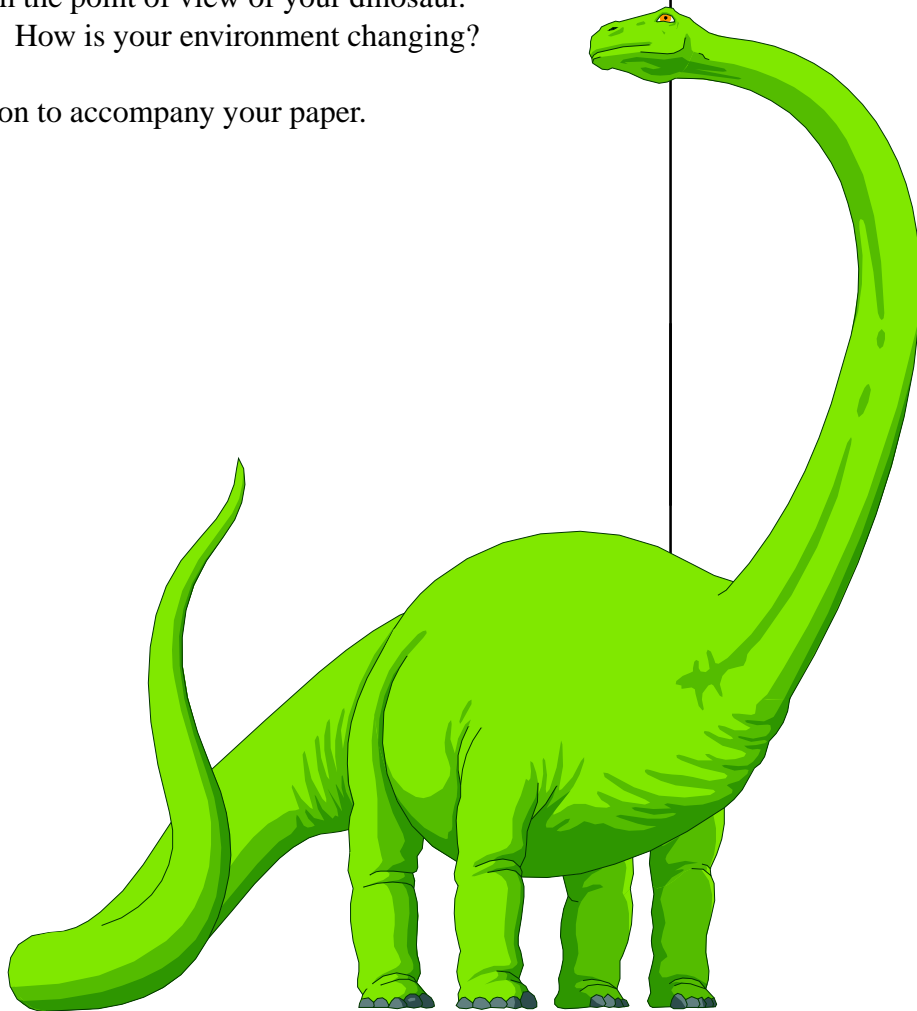
The time is sixty-five million years ago. A huge meteorite has hit the Earth. Imagine that you are a dinosaur and you notice things seem different!

Write a paper from the point of view of your dinosaur.
How do you feel? How is your environment changing?

Make an illustration to accompany your paper.

About This Activity

Students will write and illustrate a narrative from the point of view of dinosaurs as a meteorite struck the Earth sixty-five million years ago.



Atmospheric Changes Data Sheet

Describe lab setup.

What will happen to the temperature in the chamber containing smoke particles?

Chamber	Starting Temperature <i>(chambers must be equal)</i>	Time_____ <i>Record Temp Below</i>	Time_____ <i>Record Temp Below</i>	Time_____ <i>Record Temp Below</i>	Time_____ <i>Record Temp Below</i>
# 1					
# 2					

What happened in the chambers and why?